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GEOLOGICAL ARGUMENTS SUGGESTING A PACIFIC ORIGIN FOR THE CARIBBEAN PLATE

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ABSTRACT

In conjunction with an accurate assessment of relative motions between North and South America, seven arguments are presented that individually suggest that the Caribbean Plate has come from the Pacific realm to arrive at its present location after a long, relative eastward journey between the Americas. In a mantle reference frame, most of the relative motion has been due to westward translation of the Americas. While none of the seven arguments definitively proves Pacific provenance, none of the individual arguments can be explained adequately by more fixist, local (in situ) models for the origin of the Caribbean Plate. Therefore, the evidence is overwhelmingly in favor of a Pacific provenance, such that relative eastward migration of the Caribbean Plate to its present position occurred from Late Cretaceous to Recent times. Accordingly, field/marine studies and tectonic interpretations of local areas around the Caribbean must continue to test this hypothesis and attempt to reconcile what effects or implications a Pacific origin and relative eastward migration history may have had on the geological development of such areas.

INTRODUCTION

Pindell et al. (1988) defined the relative motion history between continental areas of the North and South American plates bordering the Caribbean. Their findings showed that relative plate divergence between North and South America occurred from Late Triassic to Late Cretaceous time (Early Campanian or just prior to Campanian), in a southeastward (present coordinates) direction. Since anomaly 34 time, or Early Campanian, relative motion has been either absent or minor. Motions between anomaly M-25 (Late Jurassic) and M-0 (Aptian) are well defined, but some uncertainty exists during the Cretaceous Quiet Period (Aptian to Santonian time). From the Early Campanian (anomaly 34) to the Eocene, relative motion is well constrained and was nearly absent. Since the Eocene, extremely slow north-south convergence has occurred, with the magnitude of motion increasing westwards away from a pole of rotation east of the Lesser Antilles. In the absence of significant magnitudes and rates of relative plate motion between adjacent parts of the North and South American Plates since the Campanian (Pindell et al., 1988), a distinct plate boundary probably has not existed between the two, and intense deformations within the Caribbean region since that time are likely due to tectonic interactions between the continental portions of the Americas with the Caribbean Plate, and not to motions between North and South America.

Caribbean plate evolution, having occurred within mainly oceanic terrains with all its arc magmatism, structural shortening at thrust belts, and evidence of strike-slip deformations, must have occurred within the above kinematic framework of the American plates. Two groups of tectonic models have evolved over the last two decades, one that views the Caribbean plate as having mainly developed between the Americas with only minor Cenozoic motion relative to the Americas (Klitgord and Schouten, 1987; Donnelly, 1989), and another that calls for a Pacific provenance for the Caribbean and subsequent long-distance migration into an oceanic gap (Proto-Caribbean seaway) between the Americas during Late Cretaceous and Cenozoic time (Wilson, 1966; Malfait and Dinkleman, 1972; Dickinson and Coney, 1980; Pindell and Dewey, 1982; Burke et al., 1984; Pindell and Barrett, 1990). In this paper, arguments are presented which support the latter group of models, and which suggest that a Pacific origin is necessary to understand the region's structural and stratigraphic evolution. Emphasis is placed upon possible plate boundary geometries and the existence of two unrelated suites of rock in the Caribbean, an autochthonous assemblage of passive margin sediments pertaining to the Proto-Caribbean seaway (Yucatan, northern South America, and the Florida/Bahamas Embankment), and an allochthonous collage of diverse rocks pertaining to the arcs and oceanic basement of the Caribbean plate itself. In onshore areas, a rough line can be drawn between these two suites, although sediments of the autochthon and syn-orogenic sediments are often incorporated in the thrusts that developed between the two suites during juxtaposition. Such rocks could be considered para-autochthonous.

ARGUMENTS FOR A PACIFIC ORIGIN FOR THE CARIBBEAN PLATE

1. Eastern Caribbean Volcanism

The Aves Ridge and Lesser Antilles volcanic arc complexes, although separated by the Grenada (intra-arc) Basin, collectively form the eastern portion of the Caribbean Plate. Intermediate magmatism and presumed subduction beneath these arcs (Figure 1) occurred in Upper Cretaceous-Paleogene and Eocene-Recent time, respectively (see data compilation, Figure 6, Pindell and Barrett, 1990). Polarity of subduction is clear for the Lesser Antilles arc (eastward facing arc, westward dipping subduction) based on seismicity, trench/Benioff zone morphology, accretionary prism, etc., but less clear for the Aves Ridge arc. Despite Donnelly's (1989) suggestion that the Aves Ridge was a west-facing arc based on a down to the east deepening of the eastern Venezuelan Basin's basement (possible former trench in his interpretation), such an eastward deepening of this basement is to be expected simply due to the load imparted on the eastern Venezuelan Basin from the magmatic/volcanic development of the arc. In favor of continuous westward dipping subduction, the Aves Ridge is located directly behind the Lesser Antilles arc, the latter of which began to develop immediately after volcanism had ceased in the Aves Ridge; a period of intra-arc spreading in the Grenada Basin during the Paleogene is the likely explanation for the shift in the active volcanic axis (Tomblin 1975; Speed and Westbrook, 1984). Furthermore, the Aves Ridge is slightly convex eastward, and there is no evidence for an accretionary prism along its west flank, as would be expected had subduction ever been from the west. Thus, most evidence indicates that a long, continuous history of westward dipping subduction of Atlantic crust has occurred beneath both the Aves Ridge and Lesser Antilles arcs since the early Late Cretaceous. In the framework of North and South American relative plate motions, this would require

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eastward migration of the Caribbean Plate between the Americas from somewhere to the west. Assuming (1) an 80 million year period of subduction, as suggested by the isotopic and stratigraphic ages of arc magmatism, and (2) that a convergence rate of at least 10 mm/yr is required to produce arc magmas, a 800 km convergence is suggested for this arc system as an absolute minimum.

2. Cayman Trough and Strike-Slip Basins of the Northern Caribbean

Assessments of the history of the Cayman Trough (Rosencrantz et al., 1988; Wadge and Burke, 1983) and of the Tabera and northern San Juan Basins onshore Hispaniola (Mann et al., 1984; Dolan et al., 1990) and the "Eocene Belt" of Puerto Rico (Erikson, 1988; Erikson et al., 1990) suggest Late Eocene and Oligocene east-west, sinistral strike-slip motion in the northern Caribbean (Figure 1), in addition to similar Neogene motions which are more readily accepted (Speed, 1985; Donnelly, 1989). Offset on the order of 1000 km since Late Eocene is indicated from the length of the deeper, probably oceanic portion of the Cayman Trough, and from reconstructions of Cuba, Hispaniola, Puerto Rico and the Aves Ridge arc fragments into a single Greater Antillean arc (Pindell and Barrett, 1990; Draper and Barros, 1988). Such a relative motion history is expected judging from the Eocene to Recent volcanic activity of the Lesser Antilles arc.

3. Caribbean vs. Proto-Caribbean Stratigraphic Suites

Medial Cretaceous (Albian-Santonian) portions of the stratigraphies of two suites of rock in the Caribbean are genetically incompatible as presently juxtaposed (Figure 1). One suite, here called the Caribbean suite, occurs in most of the Caribbean islands/Central America, allochthonous thrusts in northern Colombia and Venezuela (such as Villa de Cura Complex), and the internal Caribbean Plate. The second suite, here called the Proto-Caribbean suite, occurs in the autochthonous sequences (overthrust by the Caribbean suite) of Yucatan (Maya Block), Florida/Bahamas, and the northern South American margin (passive margins of the original Proto-Caribbean Sea between the Americas; Pindell, 1985). The Caribbean suite, particularly the magmatic arc portions, is dominated by intrusive and volcanic rocks, volcanogenic sandstones, tuffs and minor limes often above Albian? and older metamorphic basement. In contrast, the Proto-Caribbean suite consists of Pre-Mesozoic basement, mainly Jurassic rift-related deposits, and Cretaceous non-volcanogenic shelf sediments, all overlain by clastics of various foredeep basins of Upper Cretaceous and Cenozoic age along the suture or boundary with the Caribbean Plate (Pindell, 1990). Of primary interest here is that evidence for volcanism (flows and more importantly tuffs) is predominant in the Caribbean suite, whereas evidence for volcanism is nearly absent in the Proto-Caribbean suite of rock. Thus, spatial separation during medial Cretaceous time (prior to Campanian) seems necessary to account for this primary difference. As this difference extends from around the Caribbean sea westward to at least the Guajira Peninsula of Colombia and to Chiapas, Mexico, it is probable that the Caribbean Plate was situated farther to the west, i.e. the Pacific, during medial Cretaceous time.

4. Geometrical Incompatibility Between a Pre-Aptian? Caribbean Plate and the Aptian Proto-Caribbean Seaway

Numerous faunal and isotopic dates have been obtained from rocks in areas presently encircling or formerly part of the Caribbean Plate (e.g., rocks from Costa Rica, Panama, Siquisique Complex, Venezuela, Curacao, Bonaire, La Blanquilla, Tobago, La Desirade, Bermeja Complex, Puerto Rico, Duarte Complex, Hispaniola, arc-related basement complexes, Cuba; see Donnelly, 1989 and references cited therein for review). A pre-Aptian age is not yet proved for the central portion of the plate (Colombian and Venezuelan Basins), as DSDP drilling has reached only Coniacian sediments and volcanics (seismic horizon B") that overlie a thick sequence of layered strata with intermediate velocities (Stoffa et al., 1981). Because of the pre-Coniacian (pre-layer B") layering and intermediate seismic velocities, it is not likely that horizon B" represents oceanic crust. Rather, the Caribbean crust is probably similar to western Pacific examples of areas of anomalously shallow oceanic plateaux where medial Cretaceous, off-spreading axis basalts and sediments overlie an older oceanic basement. If so, like the areas mentioned above, the entire Caribbean Plate may be pre-Aptian in age. However, plate separation between North and South America by Aptian time (marine magnetic anomaly M-0) and the production of the Proto-Caribbean Seaway was far insufficient (Figure 1) to have accommodated a Caribbean Plate approaching its present size (Pindell et al., 1988). In the absence of very large areas in the Caribbean having been produced by seafloor spreading, or by stretching of existing crust, after the Aptian, the Caribbean Plate must have been positioned (and presumably was formed) outside the present Caribbean area (i.e., Pacific) during Aptian time and older.

5. Truncation and Uplift of the Southwestern Margin of Mexico

Structural trends of the southwest margin of Mexico have been truncated either by subduction erosion (subduction of former forearc areas) or by strike-slip removal of forearc areas to the northwest or to the southeast (King, 1969; Anderson and Schmidt, 1983). In addition, the Trans-Mexican Volcanic Belt arc (King, 1969) is mainly Neogene in age, with volcanism commencing earlier in the west than in the east, implying an eastward migration of arc inception. Paleogene arc rocks in Mexico are largely restricted to the west, in the Sierra Madre Occidental. In the Chortis Block of Central America Paleogene arc activity is abundant, with volcanism extending back into the Cretaceous (see compilation in Pindell and Barrett, 1990). As pointed out by Wadge and Burke (1983), the Paleogene arc sequences likely were continuous from western Mexico into Chortis, prior to eastward strike-slip offset of Chortis to its present position (Figure 1) and progressive development of volcanism in the Trans-Mexican Volcanic Belt. In addition to the offset of the Paleogene arc, the Precambrian basement of the southwestern margin of Mexico (King, 1969) has yielded cooling ages that indicate uplift and erosion since Oligocene time (Damon and Coney, 1983). All of these observations are best explained by a model of continuous eastward migration of the Caribbean Plate, including the Chortis Block, relative to North America (Figure 1) during latter Cenozoic time (e.g., Wadge and Burke, 1983; Pindell and Dewey, 1982). Specifically, the eastward migration of the trench-trench-transform triple junction (Mexican Trench, Middle America Trench, Motagua/Polochic transform zone) since the Oligocene or Eocene would (1) truncate the basement of southwest Mexico, (2) provide a mechanism for the progressively eastward inception of arc magmatism in the Trans-Mexican Belt coeval with continued magmatism in the Chortis Block, and (3) cause uplift of the former northern wall of the transform margin during the onset of subduction behind the migrating triple junction.

6. Faunal provinciality: Pacific vs. Proto-Caribbean Realm

According to Johnson and Kauffman (1989; this volume; pers. comm., 1990), two differing faunal realms exist across the Mexican-Caribbean region that remained distinct until beginning to merge in Campanian time, indicating spatial separation of shallow water organisms prior to that time. The areas of occurrence for the two realms nearly exactly match the areas defined above for the two differing stratigraphic suites (Figure 1) of the Caribbean Plate and Proto-Caribbean Seaway (argument 3). Mexico, Chortis, and the Cretaceous Antilles define a more "Pacific" realm (see also Montgomery, this vol., for a discussion of Puerto Rican (Greater Antillean) cherts), whereas the carbonate or terrigenous passive margins of the Bahamas, eastern Yucatan, and northern South America define a Proto-Caribbean (Atlantic) faunal realm. The Campanian initiation of faunal merging of the two realms presumably is at least partially due to tectonic juxtaposition of the shelfal (and adjoining land) areas they occupied, during the relative eastward migration of the Caribbean Plate between the Americas.

7. Initiation of Foredeep Basins Around the Proto-Caribbean Seaway

Seafloor spreading and plate separation ceased between North and South America at about Campanian time. After this, the oceanic area and the margins of the Proto-Caribbean Seaway continued to subside thermally, probably without a central spreading center (Pindell et al., 1988). North and South America essentially were part of a greater American Plate, with no significant plate boundary between them. As such, this oceanic basin would be expected to undergo a rapid load subsidence just ahead of the Caribbean Plate as it migrated progressively relatively eastwards across the Proto-Caribbean crust. In addition to the oceanic areas, adjoining shelf margins would undergo this load subsidence as well, for a distance of about 400 km "into" the passive margins (Yucatan, Bahamas, northern South America). As outlined in Pindell et al. (1988), foredeep basins with clastic flysch deposits developed at the onset of such subsidence around the Proto-Caribbean, as a direct consequence of the arrival of Caribbean crust at various portions of the Proto-Caribbean passive margins during this eastward migration. Specifically, the onset of rapid subsidence of previously shallow water areas and clastic flysch deposition occurred in northern Guatemala during the Campanian, in northern Cuba during the latest Cretaceous-Middle Eocene, in the Maracaibo area of Venezuela/Colombia in the Eocene, and in the Eastern Venezuela Basin during the Miocene (Pindell, 1990). The progressive eastward development of these basins (Figure 1) records the eastward migration of the Caribbean Plate across the Proto-Caribbean (Atlantic) Seaway, presumably from an origin within the Pacific realm. A total migration of about 1500 km since the Campanian, at rates of about 20 mm/yr average, is indicated from the development of these basins. Such a rate is in agreement with predictions of migration rate back into the Eocene from direct assessments of the Cayman Trough (Rosencrantz et al., 1988).

CONCLUSIONS

Although none of the above seven arguments for a Pacific origin of the Caribbean Plate is definitive proof for such an origin, none of the individual arguments can be adequately explained by more fixist models of plate boundary evolution within the Caribbean area (in situ origin). Therefore, the evidence is overwhelmingly in favor of a Pacific provenance. In the kinematic framework of Pindell et al., (1988), the first-order development of the Caribbean region is explained by using a perfectly rigid and non-deforming Caribbean plate during its eastward relative advance between the Americas since the Late Cretaceous. I see no need to impose ad hoc models for Caribbean evolution that do not adhere to the tenets of plate tectonics, i.e., ones that require internal deformations of oceanic crust on the order of hundreds of kilometers with little or no bathymetric expression of deformed zones, to explain the strong evidence of eastward translation that is clearly observable in some areas but less so in others. In light of a highly probable Pacific origin for the crust of the Caribbean Plate (except the oceanic floors of the Yucatan, Cayman and Grenada Basins which formed within the Caribbean Plate itself during migration), field/marine studies and tectonic interpretations of local areas around the Caribbean must continue to test the Pacific-origin hypothesis and attempt to reconcile what effects or implications, if any, a Pacific provenance may have had on the geological development of such areas.

Acknowledgements: The above arguments have developed over many years of interaction and geological synthesis among dozens of Caribbean workers, and it would be difficult to acknowledge everyone who has provided input. Particularly critical steps forward in the understanding of Caribbean evolution, however, have come from progressive refinement of the definition of relative motions between Africa and North and South America, and from studies indicating strike-slip motions in the Caribbean plate boundary zones, which have provided an increasingly accurate plate-kinematic framework for the Caribbean region in which a variety of other types of work can be set. Such studies now indicate that the primary, post-Campanian deformations of the Caribbean plate and its American continental borders pertain to interactions of the Caribbean Plate with the margins of North and South America, and not to motions between the two American plates themselves, as was once thought. Those who have helped in this refinement include John Ladd, Kim Klitgord, Steve Cande, Kevin Burke, Walter Pitman, John LaBrecque, Bill Haxby, John Dewey, Dave Rowley, Hans Schouten, Eric Rosencrantz, Paul Mann, Johan Erikson, Jim Dolan, Carlos Schubert, others. In addition, this refinement is largely responsible for the realization of the magnitude of the allochthoneity of rocks of the Caribbean Plate relative to the American margins, and for the recognition of the potential complexities of plate boundary developments in the northern and southern Caribbean. Like the Mediterranean and Asian regions, the Caribbean is an example where the geology is sufficiently complex to demand the deductive use of marine plate-kinematic assessments to provide first-order constraints on local development, upon which more local data sets and studies may be iteratively integrated.

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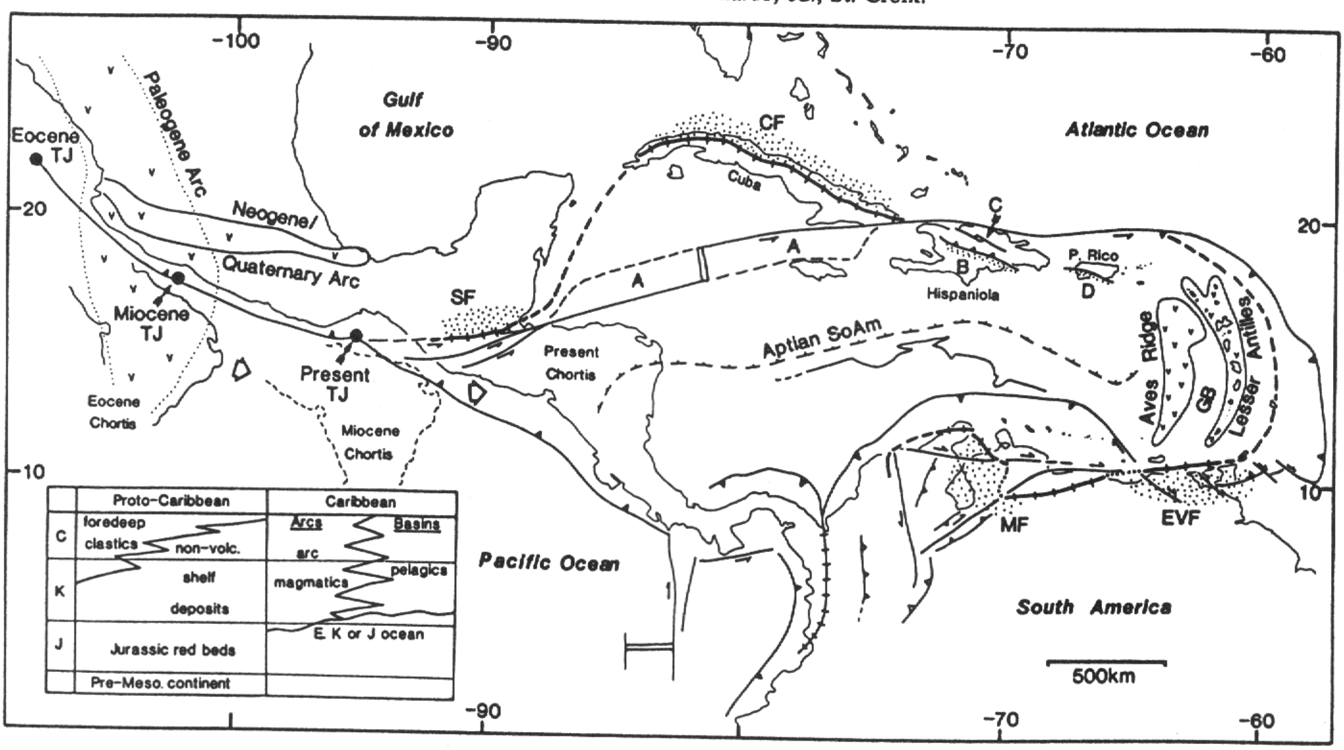

Fig. 1. Map with arguments/features discussed in text. Light lines = Present plate boundaries. Heavy lines = sutures between Caribbean arc/oceanic rocks and Proto-Caribbean shelf/foredeep rocks. Eastern Caribbean volcanism (argument 1) shown at Aves Ridge and L. Antilles. GB = Grenada Basin. Tertiary strike-slip basins (argument 2) = A, Cayman; B, San Juan; C, Tabera; D, Eocene Belt. Differences in Caribbean/Proto-Caribbean sections (argument 3), inset. Aptian S. American relative position (argument 4) = "Aptian SoAm". Migration of Chortis and TTF triple junction (TJ) (argument 5) shown SW of Mexico. Pre-Campanian Pacific/Proto-Caribbean faunal boundary (argument 6) matches suture zones. Foredeeps (argument 7) = dotted areas: SF = Sepur; CF = Cuban; MF = Maracaibo; EVF = Eastern Venezuelan.